Modelling nearshore dynamics at Norte beach (Nazaré)

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Abstract: Understanding hydrodynamic forcing and sediment transport processes is of main importance in the nearshore morphodynamic studies. This work aims to evaluate sediment transport conditions at Norte beach nearshore zone under low energetic wave conditions (Hs<1.5 m). Hydrodynamic and morphological modelling using the Delft3D software was applied at a 10 by 4 km area comprising the Norte beach and Nazaré bay, which was discretized by a curvilinear grid with 10 homogeneous sigma layers. Model results were validated with field data, including ADCP data acquired at the inner shelf and drogues released at the breaker zone. Results show a well-developed longshore current with magnitude and direction in good agreement with field observations. Estimated maximum bed shear stress provided insights on the sediment threshold potential across the study area. Sediment transport, both suspended and bed load, was found to be relevant only at the breaker zone and its vicinity.

Key words: sediment transport, nearshore dynamics, Norte beach, numerical modelling

1. INTRODUCTION

Studying nearshore wave and current dynamics together with the sediment transport processes is vital to understand shoreline evolution, the impact of nearshore structures (such as coastal protection structures, submarine outfalls and wave energy acquisition systems), the effect of offshore sand extraction and also on the impact on submarine cables (Kleinhans, 2002).

Appropriate modeling tools are therefore crucial to the management of nearshore and estuarine areas. The importance of sediment dynamics in coastal interactions further emphasizes the need for hydrodynamic and sediment transport modeling (Amoudry and Souza, 2011).

This work aims to evaluate oceanographic and sediment transport conditions at Norte beach under low energetic wave conditions (Hs<1.5 m). To meet this objective the present study is supported by the numerical modeling of the hydrodynamic and morphodynamic conditions over the Nazaré inner shelf area (Fig. 1).

1.1. Study area

The study site is located at the Portuguese west coast and it is fully exposed to the high energetic NW North Atlantic swell and the locally generated sea that is characterized by a wide directional spreading (from N to SW octants). Offshore incident wave regime is characterized by significant wave height of about 2 m and average peak period of 11 s (Dodet et al. 2010).

The target area is located at the vicinity of the Nazaré submarine Canyon and is presently being studied in the scope of several research projects (Duarte *et al*., 2014, Silva *et al*., 2012). This coastal stretch exhibits a particular behavior with the interaction of wave and currents with the complex morphology of the Nazaré canyon head.

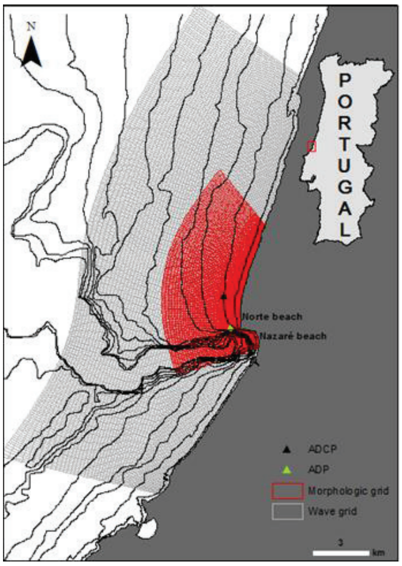

Fig. 1. Morphologic and wave grid for Delft3D simulation and the position of ADCP and mini-ADP.

2. METHODS

2.1. Fieldwork

The field data was acquired under the scope of the Beach to Canyon project (PTDC/MAR/114674/2009) during the main field campaign that took place at Norte Beach between 9th and 15th September 2013. The experiment consisted on the estimation of the longshore drift through the continuous injection of 10 tons of native coated sand. During the tracer injection procedure (approx. 5 hours), drogue release was performed at several sites along a rectilinear coastal stretch extended through 600 m downdrift of the injection point (Duarte *et al.*, 2014) and inside the Nazaré Bay.

The oceanographic conditions at the inner shelf were measured throughout an ADCP deployed at 16 m depth in front of the Norte beach and a mini-ADP deployed off Nazaré headland at 18 m depth (Fig. 1). Longshore current was estimated by a series of drogues (oranges) that were released approximately at the breaker point along the Norte beach. Sedimentary and topographic data were also collected along the study area.

2.2. Numerical modelling

The 3D hydrodynamic model was first configured through the use of Delft Dashboard software - a standalone Matlab based graphical user interface to the Delft3D modelling suite (Lesser *et al.*, 2004). This interface eases model setup in what concerns hydrodynamics, waves, sediment transport and morphodynamic conditions.

Model domain consists of two computational grids (Fig. 1). The wave grid covers an area of 24600 x 9200 m discretized in a curvilinear grid with a resolution that increases from 200 m offshore up to 60 m towards the coast. The flow grid has 9000 x 4300 m and it is also represented by a curvilinear grid with a cell size from 170 m up to 14 m. Both grids contains 10 homogeneous sigma layers (10% of the local depth for each layer). The bathymetry and topographic data represent the morphological configuration during summer.

The boundary conditions were imposed using the Topex 7.2 tidal model and by a parametric wave spectra (H= 1.2 m; T=8 s; Dir = 330°) which was considered the average wave regime in this area during the field campaign (as measured by ADCP).

The effect of the enhanced bed shear stress due to the wave–current interaction was computed using the Fredsøe (1984) model, parameterized by Soulsby (1997). Both suspended and bedload transport were computed using the Soulsby/Van Rijn method (Deltares, 2011).

3. RESULTS

3.1. Validation

Longshore drift

The longshore current measured by drogues along the surf zone was southward directed with velocities ranging between 0.16 and 0.55 m/s.

The model results at the observed points located at 2 m depth are in agreement with field data regarding both direction and magnitude of the longshore drift (Fig. 2). The model results were also able to represent the slight decrease of the longshore current intensity approximately at a 400 m downdrift distance from the sand injection point.

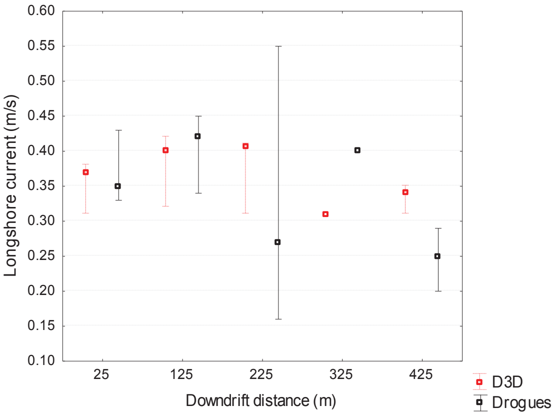

Fig. 2. Boxplot graph comparing the field measurements (drogues) and numerical modelling results (D3D) of the longshore current magnitude represented by maximum, minimum and medium vzlues. Single points indicate a single measurement.

Inner shelf current

Both ADCP and mini-ADP current data show a moderate uniformity along the water column and a tide correlated flow pattern. The along-shelf current is dominated by the north-south current (v component) and it is clearly the strongest current component acting at both measurement sites with a prevailing northward directed flow reaching up to 0.16 m/s (Fig. 3 and Fig. 4).

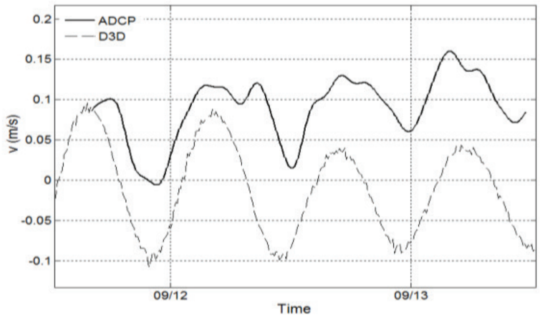

Fig. 3. Comparison between the north-south current measured by the ADCP and simulated by the Delft3D model (D3D).

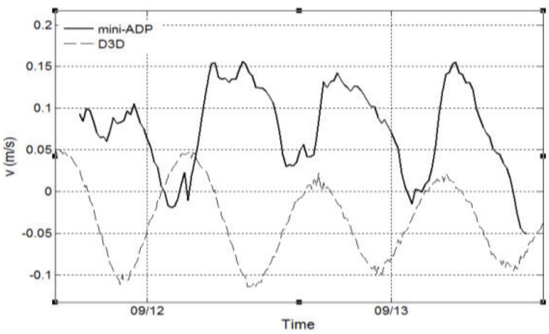

Fig. 4. Comparison between the north-south current measured by the mini-ADP and simulated by the Delft3D model (D3D).

The model results also show a tide related along-shelf current, however with a prevailing southward direction and magnitudes up to 0.1 m/s.

The differences between observed and simulated current data are probably due to the presence of a northward residual flow described as a poleward coastal flow compatible with the presence of an inshore countercurrent that is associated with periods of weakening/relaxation of upwelling favourable winds (Relvas and Barton, 2002). This phenomena cannot be simulated by the model as only tidal and wave forcing are being considered.

The smooth bathymetry in the vicinity of the ADCP measure site supported a good behavior of the hydrodynamic model over this area. Fig. 3 shows a good agreement in phase and magnitude between simulated and observed current data. On the other hand, the complex bottom configuration of the canyon head at the proximity of the mini-ADP observation site clearly affects the numerical model simulation at this area. The tidal signal could not be correctly simulated over the canyon head as the hydrodynamic grid contains only part of this morphological feature. This aspect has probably influenced the phase lag between simulated and observed along-shelf current data.

3.2. Model results

The model output clearly shows the wave deformation across the propagation area (Fig. 5).

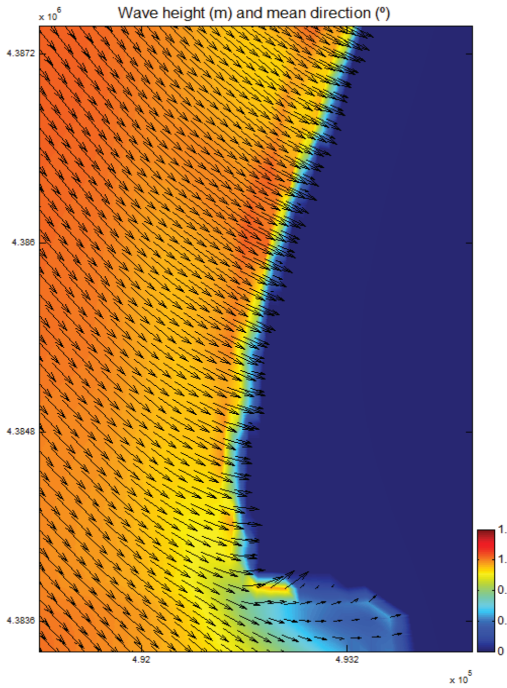

Fig. 5. Wave propagation across the study area (2013-09-12 15:00).

The coastline configuration and Nazaré headland shelters the Nazaré embayment inducing a milder wave regime at the Nazaré beach. Through the coastal stretch north of Nazaré headland, the changes in wave refraction pattern are related to the progressively smaller wave breaking angles northward from the headland.

According to Delft3D computation, the spatial distribution of the horizontal velocity of the upper layer indicates a well-defined southward longshore current. Across the coastal stretch north of Nazaré headland the current velocity varies mostly from 0.3 up to 0.7 m/s. The nearshore current transposes the headland and follows the coast eastward with velocities between 0.2 and 0.4 m/s. At Nazaré beach currents are weaker and do not exceed 0.2 m/s (Fig. 6).

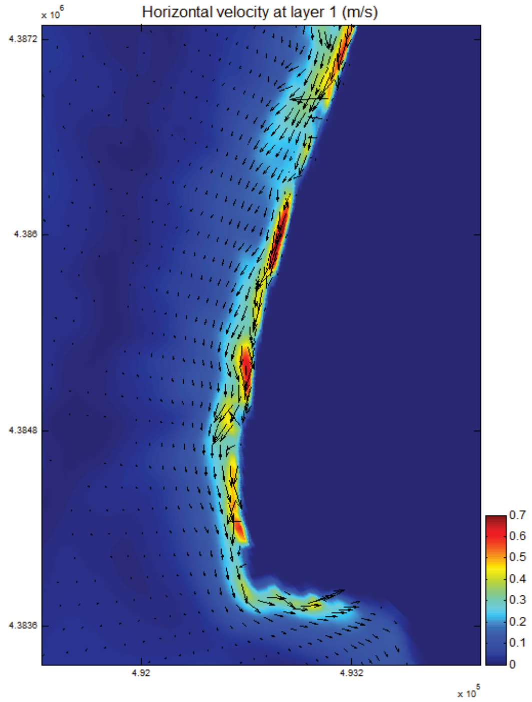

Fig. 6. Horizontal velocity at the upper layer (2013-09-12 15:00).

The spatial distribution of the maximum bed shear stress gives a good insight on the determination of the potential area for sediment remobilization. Based on the numerical modelling results of the wave-current interaction, thresholds for two particle sizes were determined in order to estimate the areas. According to the numerical simulation, in low energy conditions, coarse sand can be mobilized up to 16 m depth while fine sand threshold is around 35 m depth (Fig.7).

The suspended and bed load transport rates computed for medium sand (D_{50} = 0.4 mm) indicates that during low energetic conditions the sediment transport is restricted to the breaker zone and its vicinity. Both transport rates are of the same magnitude and have a very similar spatial distribution pattern (Fig. 8).

4. DISCUSSION AND CONCLUSIONS

This work was able to evaluate the sediment transport conditions at Nazaré beach nearshore zone under low energetic conditions through a 3D numerical simulation performed by Delft3D.

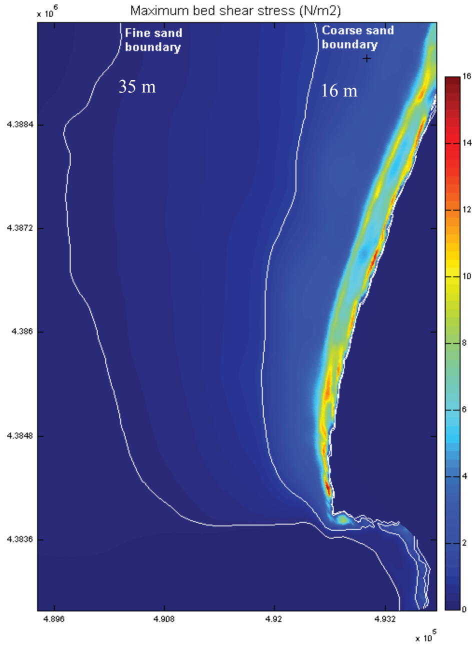

Fig. 7. The spatial distribution of the maximum bed shear stress with maximum threshold depth for fine and coarse sand (2013-09-12 15:00).

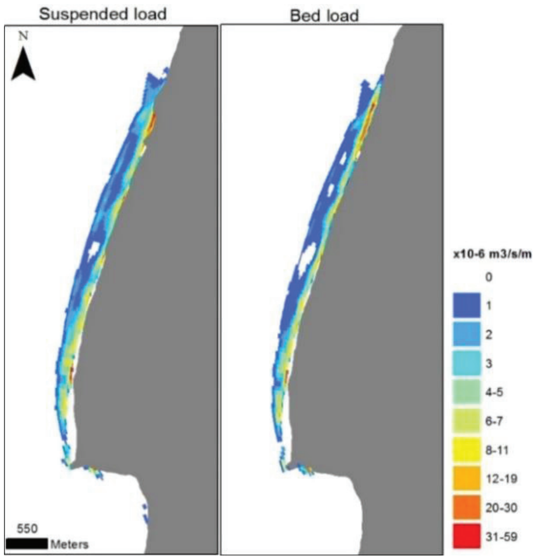

Fig. 8. The instantaneous transport rate represented by the suspended and bed load (2013-09-12 15:00).

Longshore drift estimates shows a wave-induced southward directed flow, with a magnitude similar to the ones measured in the field. This result is in agreement with Larangeiro (2012) work where a southward longshore current was computed under similar wave forcing type. Flow simulation also indicates the headland eastward shifting of the longshore southward current that persists near the coast, identifying a condition of sediment headland bypassing.

Model results also gave valuable insights on the understanding of the sediment dynamics at the inner shelf by the computation of maximum threshold depths for fine and coarse sand in relation to wave-current forcing.

The transport rates for the suspended and bed load simulated over a medium sand sedimentary bed allowed the evaluation of longshore drift behavior during low energetic condition.

Future work will focus on the validation of the transport rates with the sand tracers results. Further efforts should also be done in order to expand the numerical modelling of the nearshore dynamics to other energy conditions acting over the study area.

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